

Hybrid Protection based on Pyroswitch and Fuse Technologies for DC Transportation

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Abstract – Fuses and Circuit Breakers play an important safety role in electrical transportation systems. New challenging applications, especially in DC applications, have brought conventional current limiting devices to their limits. Indeed, mechanical circuit breakers may be too slow to open for networks with large DC fault current. As well, fuses may be too slow to open with very low DC fault current. In DC applications, the no natural crossing is challenging fault clearing by conventional current limiting technologies. This paper presents a new solution to protect DC transportation using a fuse and pyroswitch hybrid system. This will apply to PV generation, energy storage, Electrical Vehicle...

1. INTRODUCTION

Historically, fuses and mechanical circuit breakers, general purpose and fast acting, have been the choice for over current protection devices. Furthermore, each time electrical applications reached new steps and brought up new challenges in fault clearing, these were answered by solutions including fuses and/or breakers or a combination of both. Is it still the case today?

Current-limiting fuses are low cost solution, easy to install, fast operating and reliable current breaking devices when used within its current-limiting rating. In most cases they can effectively limit short circuit currents to a value much lower than that would have flown in the circuit.

Circuit breaker are widely used for short-circuit protection. Their ability to be resettable is a major advantage against fuse. When the fault is detected, it features a slower time response than current-limiting fuses to operate due to the large mechanical time constant. In DC networks, arc presence leads to contact erosion and arcing chamber fatigue, consequently to a shorter lifetime combined to high maintenance costs.

Nowadays, the challenge for MERSEN is to develop new systems which respond to DC transportation requirements [1-5]. As seen before, the conventional current limiting devices have been brought to their limits. Fuses and CB are asked for improving and adapting the technologies, but nevertheless always based on the same fundamental principle. This paper presents a new solution based on fuse and pyroswitch components that may answer new distribution trends. The principle of this current limiting device will be described and the testing performance results will be presented.

2. NEW OVER CURRENT PROTECTION

2.1. Pyroswitch

Pyrotechnic safety devices took off in the early 1990's in the automotive industry with the introduction of the first Airbags in European vehicles steering wheel. The pyroswitch is an electrical interrupter and in contrast to a fuse, the time to achieve a complete disconnection of a circuit will not be dependent on the magnitude of the over-current. In general, pyroswitch utilizes a miniature guillotine that is propelled by a pyrotechnic charge to achieve the force required to cut through a metallic conductor (bus bar). This gives a very simple and thus extremely reliable property [6-8].

A pyroswitch alone is compatible with medium power devices (electric device) $I \sim 400$ A and $V \sim 50$ V. Indeed, the increase in intensity will require increasing the section of the bus bar, thus increasing the energy of the disconnecter. Similarly the increase in tension will require more separate conductors and thus complicate the device.

Even if pyroswitch has the advantage it is faster operating than strictly mechanical apparatus and is much less expensive than are purely electrical breakers in high load applications, this kind of device suffers from several drawbacks. Notable of these is the risk of harmful arcing when cutting off an inductive circuit. A simplified explanation for this is that the circuit with inductive current is reluctant to change. This reluctance causes a harmful arc to develop between two formerly connected conductors at the moment of disconnection. While the reasons for these deficiencies are not straightforward to understand, explosive breakers under high loading may be due to their inability to rapidly turn-off the ionization between severed electrode parts. It is therefore one object of this paper to provide a high speed, high voltage hybrid circuit breaker capable of minimizing system exposure to the circuit faults.

2.2. Hybrid solution: Pyrofuse

This section presents a new hybrid protection solution, in which a pyroswitch element and a fuse element are configured electrically in parallel. Figure 1 shows the pyroswitch (grey) and the fuse (white).

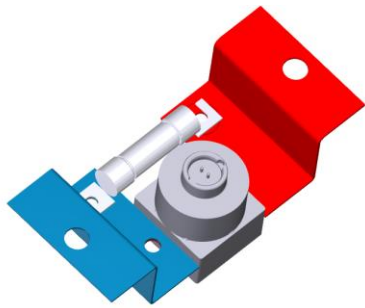


Figure 1: New hybrid protection solution with pyroswitch and fuse

Figure 2 presents electrical schematics of the pyrofuse. The fuse F1, the pyroswitch P1 and the triggered electronic are depicted. During the lifetime, the global device is closed and the nominal current is flowing. The P1 resistance (copper bar) is lower than the F1 resistance, thus the nominal current flows through P1. Cycling performance and lifetime are improved in comparison to fuses. Moreover, with the very low resistance of the pyrofuse ($\sim 200\mu\Omega$), the on state losses drastically decrease. Fuse F1 could be sized with a low nominal current caliber and a low-cost. Let's focus on the switch off. During the switch off, the pyrofuse identifies a fault current thanks to current sensor (Hall Effect, shunt) and send the triggered signal to P1. As seen before, the pyroswitch systems suffer from risk of harmful arcing when cutting off a high voltage load. But in this case, F1 is situated in parallel and is still closed. Thus P1 cut off the copper bar without any voltage. At this moment, the fault current flows through the fuse which is undersized. The fuse opens the circuit with a very short cut-off time (less than 300 μ s). The pyrofuse allows using the pyroswitch without voltage during the cut-off and the fuse with a high fault current.

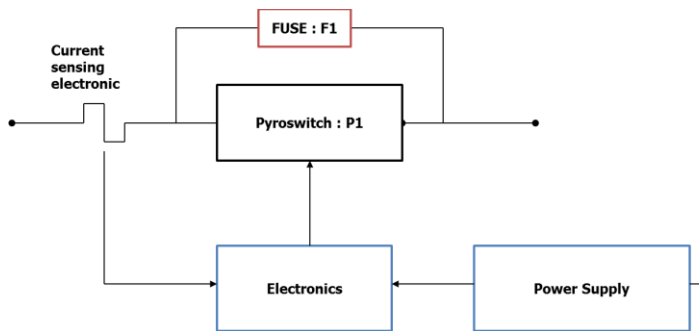


Figure 2: Electrical Schematics of the Pyrofuse

3. PERFORMANCES

3.1. On state

In order to understand the on state performances, the system has been tested under 400A. The aim of this section is to measure the losses and the temperature increase of the pyrofuse. As the resistance is very low, the temperature increase is limited as presented in the following table. The terminal connectors have a section of 240 mm² as indicated in the fuse standard.

Ambient temperature	System temperature under 400A
25°C	58°C
60°C	70°C
90°C	99°C

3.2. Short circuit

Short-circuit tests have been performed under 500 VDC, and 1000A to 7000A as fault current. The parallel fuse has a

current range of 80 A. The figure 3 presents the waveforms of the current and the voltage during the cut-off for a 4000A fault current. A special test board has been developed to initiate the pyroswitch after 100 ms. After this time, the pyroswitch opens the copper bar and the current then flows through the fuse. The global cut-off time is 1.476 ms. Other tests have been performed under 7000 A and will be presented in the final paper with the different cutting steps.

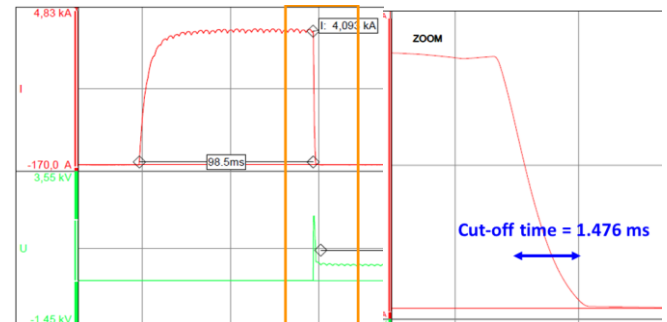


Figure 3: Current and voltage waveform (4000A – 500VDC)

4. ULTIMATE PROTECTION

4.1. Principle

As seen before, this hybrid protection shows excellent performances (cut-off time, volume, weight and cost). Unfortunately, in some applications, the current control command is not straight forward. Moreover, some protections need to be self-triggered to ensure ultimate protection of the electrical installation. All these reasons have led us to develop the self-triggered pyrofuse. The principle is to add a fuse in series (Figure 4) which is designed for the nominal current but not for the nominal voltage. This fuse is used as current sensor and power generator for the pyroswitch trigger. Indeed, when a fault current ($I > I_{F1}$) crosses F1, an electrical arc appears between the terminal. This arc is used as a voltage source by the initiator. R1 defines the current flowing in PS1. This system is self-triggered.

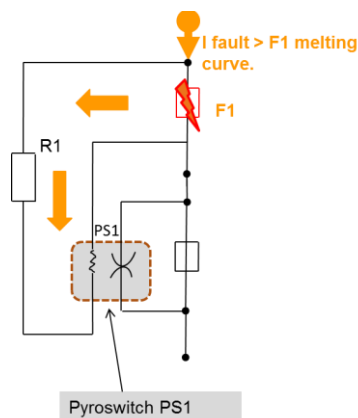


Figure 4: Self triggered Pyrofuse

4.2. Test results

This self-triggered pyrofuse has been tested under 500VDC with 11 kA fault current and the results will be presented in the final paper.

5. REFERENCES

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